# The Occurrence and Distribution of the Tube-nosed Insectivorous Bat (*Murina florium*) in Australia

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A comparison of specimens (n=14) of the Tube-nosed Insectivorous bat, *Murina florium*, from the wet tropics (15°30′–19°20′S) and an outlying specimen from Cape York Peninsula, suggests that a single species exists in Australia. A total of 26 localities have been identified using capture records and acoustic detection (echolocation and social calls). Sites occur between 60–1120 m above sea level, in rainforest or wet sclerophyll forests. A common feature at each site, or in close proximity (within 4 km), is the presence of mixed wet sclerophyll forest or a close structural equivalent. BIOCLIM modelling was used to describe the climate variation between sites and predict a distribution. The climate profile suggests that *M. florium* prefers forested areas with the following key parameters (annual average): precipitation 1852 mm (range 1197–2574 mm), rainfall in the driest period 39 mm (range 20–59 mm), temperature range of 17.7°C (range 13.9–19.0°C), maximum temperature of the warmest period 28.6°C (range 27.3–31°C). The predicted distribution of *M. florium* in the wet tropics is restricted to a relatively narrow, elongated band running approximately north-south. It corresponds to regions with a steep rainfall gradient, largely on the western side of mountainous areas and several plateaus, and encompasses the upland wet sclerophyll forests.

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## INTRODUCTION

The microchiropteran bat *Murina florium* was described originally from a specimen collected on the Isle of Flores in Indonesia by A.R. Wallace (Thomas 1908). Subsequently, *M. florium* has been found on numerous islands, largely to the east of Wallace's Line, as far as Papua New Guinea but records are sparse (Laurie and Hill 1954; Hill 1983; Koopman and Danforth 1989; Corbet and Hill 1992; Koopman 1993; Flannery 1995a, 1995b). *M. florium* was not discovered in Australia until 73 years after its description, when it was captured on Mount Baldy (17°17′S 145°25′E) at the western edge of the Atherton Tableland in north Queensland, during a national survey of rare and endangered bats sponsored by the World Wildlife Fund (Richards et al. 1982; Hall 1983). Then a few years later in 1986, a second locality was found nearby at Mt. Hypipamee National Park, from bats captured along a walking track (G.A. Hoye, pers. comm.; see Winter 1991). Unfortunately with only two known sites, Nix and Switzer (1991) were unable to predict the distribution of *M. florium* through climate modelling. Despite this problem, it was speculated that the species may be restricted to high altitudes such as "misty, mountainous, tropical rainforest" (Richards 1983), thereby evading capture by inhabiting areas hitherto rarely sampled for bats. A single *Murina* specimen was collected near sea level at Iron Range (12°40′S 143°21′E) in 1983 (Queensland Museum Specimen No. JM4423, collectors S. Flavel, M. Adams and C.H.S. Watts), and although not identified formally as *M. florium*, it possibly belongs to the subspecies *M. f. lanosa* (Hill and Rozendaal 1989).

The paucity of records for *M. florium*, and its perceived rarity, initially resulted in a conservation status of 'critically endangered' within the boundaries of the Wet Tropics World Heritage Area (WTWHA), from recommendations to a regional action plan (Nias et al. 1993). However, the number of records for this species have increased significantly over the last decade or so (Spencer et al. 1992; Clague et al. 1995; Kutt and Burnett 1995; Whybird 1996; Schulz and Hannah 1996) due to focussed interest in the bat fauna of the Australian wet tropics, and the refinement of capture and observational techniques (Clague 1998; 2000). As a consequence, *M. florium* has now an IUCN conservation rating of Lower Risk, near threatened (for definition, see IUCN 1994) in the recently published Action Plan for Australian Bats (Duncan et al. 1999).

The number of capture records for *M. florium* in the wet tropics region (as defined by Nix and Switzer 1991) has now reached a point where it is useful to compare the data for specimens and the biogeography of collecting localities. The aim of this paper is to present new data on the occurrence of *M. florium* in Australia, and to re-assess existing records in order to describe the known distribution. In addition, any habitat preferences for the species have been examined, and the bioclimatic modelling program BIOCLIM has been used to generate a climate profile and hence a map of predicted distribution.

## METHODS

### Records of *Murina florium*

Records of *M. florium* were obtained from museum specimens (Queensland Museum and Australian Museum), external measurements taken, and where possible details relating to the collecting locality (Table 1). Additional records were obtained by personal communication with collectors or by reference to the literature and unpublished reports.

New observations reported here were obtained from general bat surveys carried out by the authors in the Wet Tropics World Heritage Area (WTWHA) through Project Gondwana (Clague et al. 1995) and as a result of other research projects in the region (Clague 1998). Data collected during these studies were obtained from bat capture using conventional harp traps and mist nets, and by acoustic survey methods. In the latter case, the echolocation call of *M. florium* and its species specific 'audible' social call have been recorded and analysed in detail (Coles et al. 1998). Both of these vocalisations can be used to identify individual bats flying and foraging at night, and positive observations (from the analysis of tape recordings) have been used to provide 'acoustic detection' sites, in addition to 'capture' sites (listed in Table 2).

### Site localities and vegetation

All sites recorded for *M. florium* in Australia were visited during this study, to establish or confirm the precise location by grid reference and altitude, using satellite positioning (GPS) and topographic map sheets. The biogeography was described for new sites established in this study and, if necessary, re-assessed for the existing sites (Table 3).

TABLE 1.

External measurements of *Murina florium* specimens from Australia, Papua New Guinea (PNG) and Indonesia (Indo). Sources: Australian Museum M, Queensland Museum JM, British Museum BM, Rijksmuseum Leiden RMNH; 1 Schulz and Hannah (1996), 2 Kutt and Burnett (1995), 3 specimen measured before loss, 4 G.A. Hoye pers. comm., 5 holotype *M. f. florium* (Thomas 1908). See Table 2 for details of Australian localities and site No. For other localities see 6 Hill (1983); 7 Hill and Rozendaal (1989); 8 Flannery (1995a); 9 Flannery (1995b). Abbreviations: forearm FA, humerus Hum, thumb Th, 3rd metacarpal mc3, femur Fem, tibia Tib, hindfoot HF, head-body HB, head-body-tail HBT, ear EL, tragus Tr; measurements in mm, weight (Wt) in g.

| Site No. | Locality | Sex | Wt. | FA | Hum | Th. | mc3 | Fem | Tib. | HF | Tail | HB | HBT | EL | Tr. | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Shipton's Flat | F | 7.1 | 34.6 | | 7 | 31 | | 16.5 | 4.5 | 37 | | | 10.5 | | this study, released |
| 2 | Gap Creek | M | 7 | 34.4 | 22.7 | 9 | 30 | 12.7 | 15.2 | | 30.8 | 56.5 | 87.3 | 12.6 | 10.1 | this study, missing[3] |
| 6 | Chalumbin-Woree | M | 35.5 | | | | | | | | | | | | | released[2] |
| 7 | Mt Baldy | F | 8.2 | 35.3 | | | | | | | | | | | | released[1] |
| | | F | 9 | 35.3 | | | | | | | | | | | | released[1] |
| 9 | Mt Baldy | F | 7.9 | 35.6 | 25.2 | 10.1 | 34.8 | 15.3 | 18.8 | 3.3 | 35.8 | 42.9 | 79.1 | 13.1 | 5.9 | JM3629 |
| 15 | Mt. Hypipamee | F | 8.4[4] | 35.4 | | 10.1 | 32.7 | 13.6 | 17.5 | 4.4 | 32.6 | 46.3 | 80.4 | 12.2 | 6.7 | JM8674 |
| | | M | 7.3[4] | 34.8 | | 9.9 | 32.3 | 15 | 16.5 | 4.6 | 32.2 | 45.4 | 78.5 | 13.7 | 6.9 | JM8673 |
| 16 | Mt. Fisher | F | 6.5 | 34.9 | 13.2 | 9.6 | 29.2 | 8.8 | 16.3 | 4.7 | 315 | 5.9 | 88.7 | 12.9 | 8.3 | this study, released[1] |
| 20 | Koombooloomba | F | 6.5 | 34.7 | 15.3 | 7.5 | 32 | 8.1 | 16.8 | 5.1 | 35.5 | 46.4 | 81.8 | 12.8 | 7 | this study, released[1] |
| | | F | 6 | 34.9 | 18.2 | 6.8 | 31 | 12.4 | 17.9 | 7.5 | 32.3 | 49.5 | 80.4 | 12.1 | 7.3 | this study, released[1] |
| | | F | 8 | 34.6 | | | | | | | 34.5 | | | | | released[1] |
| | | F | 9 | 34.5 | | | | | | | 36.2 | | | | | released[1] |
| | | F | 5.8 | 32.6 | | | | | | | 34.9 | | | | | juvenile, released[1] |
| 26 | Iron Range | M | 5 | 33.1 | 22 | 9.5 | 30.9 | 15.1 | 17.7 | 3.6 | 30.6 | 38.8 | 67.2 | 11.5 | 5.6 | JM4423 |
| PNG | Mt.Somoro | M | 6.5 | 33.0 | 22.3 | 11.3 | 31.7 | 13.1 | 15.2 | 8.4 | 30.2 | 42.7 | 74 | 11.8 | 6.8 | M21732[8] |
| | Morobe Prov. | F | 7 | 34.4 | 24.4 | 12 | 32.5 | 15.1 | 17.4 | 8 | 34 | 44.6 | 75 | 11 | 6.3 | M19551[8] |
| | Variata NP | M | 6 | 34.2 | 23.9 | 12.2 | 33.9 | 15.6 | 17.6 | 9 | 39 | 42.2 | 83 | 14 | 9.0 | M15112[8] |
| Indo | Ambon Is. | M | 6 | 36.2 | 24.2 | 11.6 | 32.9 | 15.3 | 18.5 | 7.9 | 36.6 | 45 | 81.6 | 13.4 | 7.9 | M26243[9] |
| | Buru Is. | F | | 34.4 | | | | 30.5 | | | | 34 | 43 | | 14 | BM 23.1.2.27[6] |
| | Ceram Is. | F | | 37.5 | | | | 34 | | | | | | | | BM 10.3.4.24[6] |
| | Flores Is. | | 4 | 34.8 | | 14 | 31 | | | | 32 | | | | | BM 63.12.26.14[6] |
| | Moluccas | F | 5.4 | 34.3 | | | | | | | | 42 | 49 | 15 | | RMNH33381[7] |
| | Sulawesi | F | 5.3 | 32.9 | | | | | | | | | | | | RMNH33374[7] |
| | | M | 5.5 | 34.6 | | | | | | | | | | | | RMNH34894[6] |

A description of the vegetation types at each site was based on Tracey (1982), and the wet sclerophyll vegetation types were defined by Harrington and Sanderson (1994) criteria, as shown in Tables 3 and 4.

**Climate analysis and predicted distribution**

An Arcview 3.1 (Environmental Systems Research Institute, Inc., http:// www.esri-au.com.au) emulation of the predictive climate modelling program BIOCLIM (Busby 1986), was used to predict the distribution of potential *M. florium* habitat. Climate surfaces were generated, using the ESOCLIM module of ANUCLIM (http:// cres20.anu.edu.au/software/anuclim.html) and a Digital Elevation Model (DEM) with a resolution of approximately 250 m. The model was run for a region extending between 15°30'-19°20'S and 144°20'-147°00'E. This area encompasses the 'wet tropics' and the WTWHA as illustrated by Nix and Switzer (1991).

A maximum of 35 bioclimatic parameters can be used for a BIOCLIM analysis (see http://cres20.anu.edu.au/software/anuclim.html) and these are created from the climate surfaces output by ESOCLIM. The model was run for all 35 climate parameters (see Table 5) and a grid surface representing each parameter was generated for the region of interest (illustrated in Fig. 1) in order to predict the distribution of *M. florium.* Previous BIOCLIM modelling for the distribution of vertebrates the same region (Nix and Switzer 1991) suggests that there are several important rainfall and temperature parameters determining forest structure in the wet tropics. On this basis, a subset of seven parameters were selected (see Table 5) and also used to predict the distribution for *M. florium* (see Figs 1 and 2).

The complete wet tropics data set comprised 25 discrete records where individuals of *M. florium* have been either captured (n=11) or detected by acoustical monitoring (n=14) at a given locality (Table 2). Using the seven selected bioclimatic grid surfaces (parameters listed in Table 5), the distribution of *M. florium* was modelled for all localities (Fig.1), capture records only (Fig. 2a) or observations by acoustic detection only (Fig. 2b).

In the present study, each modelled distribution (Figs 1 and 2) represents the total area of grid cells that are common to all of the selected climate parameters and all of the sites. The range in value for each climate parameter generated by the DEM, across all sites used in this study, produces the complete climate profile for *M. florium* (Table 5).

The single capture site at Iron Range on Cape York Peninsula (Table 2) was regarded as an outlier for the purposes of the current BIOCLIM analysis and will be treated separately. This approach is prudent as, at present, all other known records for *M. florium* are confined to a circumscribed region in the wet tropics (see Table 2 and Fig.1) which appears to be a core of its distribution in Australia.

## RESULTS

**External morphology**

Table 1 summarises the measurements available for a range of morphological characters obtained from 14 specimens captured in Australia and nominated as *Murina florium.* A complete set of measurements is not available for all specimens due to variation in the source of the material (identified in Table 1). From the data available, all specimens conform to the key diagnostic characters of the genus *Murina* by having extended tube-like nostrils and a pelage with relatively long woolly fur, including an extension of hair onto the uropatagium especially and the wing membranes, and a relatively long thumb (Richards 1983; Koopman 1993; Richards et al. 1995; Churchill 1998). The fur colour of

TABLE 2.

Australian localities for Murina florium based on 25 sites in the wet tropics and a single site on Cape York Peninsula (Iron Range), identified by the nearest named feature. The type of record (Rec.) at each site is capture (c) or acoustic detection by echolocation call or social call (a). Altitude in metres (m) above sea level.

| No. | Site name | Rec | Latitude degrees S | Longitude degrees E | altitude (m) |
|---|---|---|---|---|---|
| 1 | Shipton's Flat | c | 15°46′ | 145°13′ | 245 |
| 2 | Gap Creek | c | 15°48′ | 145°19′ | 245 |
| 3 | Mt. Windsor Tableland | a | 16°17′ | 145°05′ | 840 |
| 4 | Mt. Carbine Tableland | a | 16°27′ | 145°11′ | 914 |
| 5 | Gordonvale | a | 16°57′ | 145°49′ | 70 |
| 6 | Chalumbin–Woree | c | 16°58′ | 145°39′ | 650 |
| 7 | Mt. Baldy | c | 17°16′ | 145°25′ | 1090 |
| 8 | Mt. Baldy | a | 17°16′ | 145°25′ | 1000 |
| 9 | Mt. Baldy | c | 17°16′ | 145°25′ | 1120 |
| 10 | Mt. Baldy | c | 17°19′ | 145°26′ | 1100 |
| 11 | Mt. Baldy | a | 17°19′ | 145°24′ | 1100 |
| 12 | Mt. Baldy | a | 17°19′ | 145°24′ | 1080 |
| 13 | Moomin | a | 17°22′ | 145°26′ | 1060 |
| 14 | Tinaroo | a | 17°22′ | 145°35′ | 850 |
| 15 | Mt. Hypipamee | c | 17°25′ | 145°28′ | 980 |
| 16 | Mt. Fisher | c | 17°33′ | 145°34′ | 880 |
| 17 | Mt. Fisher | a | 17°33′ | 145°35′ | 830 |
| 18 | Ravenshoe | a | 17°43′ | 145°31′ | 710 |
| 19 | Nitchiga | a | 17°47′ | 145°32′ | 762 |
| 20 | Koombooloomba | c | 17°51′ | 145°35′ | 820 |
| 21 | Koombooloomba | a | 17°51′ | 145°33′ | 760 |
| 22 | Dalrymple Gap | a | 18°23′ | 146°04′ | 200 |
| 23 | Wallaman Falls | c | 18°35′ | 145°47′ | 580 |
| 24 | Paluma | a | 19°00′ | 146°08′ | 876 |
| 25 | Paluma | c | 19°01′ | 146°08′ | 854 |
| 26 | Iron Range | c | 12°40′ | 143°20′ | 60 |

Australian *M. florium* ranges from russet brown to grey in living specimens, but preservation in alcohol makes it difficult to determine accurately. Living specimens have been noted to have fawn to bronze fur dorsally, and bicoloured fur with a black base and grey tips on the ventral surface (see also Schulz and Hannah 1996). The uropatagium is always hairy but the hairs vary in density between individuals, having a golden brown appearance.

The most complete measurements (Table 1) yield the following average values for *M. florium* specimens from the wet tropics region of Australia: forearm length 34.7 mm,

TABLE 3.

Vegetation description for 26 *Murina florium* sites (listed in Table 2). Forest type is based on the classifications of Tracey (1982) and Harrington and Sanderson (1994) where possible. Otherwise, an equivalent (equiv.) forest type, and/or distance to the nearest Harrington and Sanderson (1994) forest type is indicated. Harrington and Sanderson (1994) forest types were assessed for each site in this study. For Tracey (1982) descriptions, the source references (Ref.) are: 1, this study; 2, Richards et al. 1982; 3, Spencer et al. 1992; 4, Kutt and Burnett 1995; 5, Schulz and Hannah 1996, 1998 (description varies, see text); 6, Kutt and Williams unpublished record; 7, Whybird 1996; 8, M. McLaughlin pers. comm.; 9, J. Clarkson pers. comm. See Table 4 for summary.

| | | Vegetation Description | | |
|---|---|---|---|---|
| No. | Site Name | Tracey 1982 | Ref. | Harrington and Sanderson 1994 |
| 1 | Shipton's Flat | Complex notophyll vine forest [Type 5b], nearopen *Eucalyptus tessellaris* forest [cf Type 16h] | 3 | <1 km from Type 4 equiv. |
| 2 | Gap Creek | Complex mesophyll vine forest [Type 1a] | 3 | ~2.5km from Type 2 equiv. < 4km from Type 4 equiv. |
| 3 | Mt. Windsor Tableland | [Type14b] near Complex notophyll vine forest [Type 6] | 1 | Type 4 and 5 |
| 4 | Mt. Carbine Tableland | [Type 14] near Simple notophyll vine forest [Type 8] | 1 | Type 5, <200m from Type 4 |
| 5 | Gordonvale | Mesophyll vine forest with dominant fan palms [Type 3b] near [Type 12c] | 7 | <1 km from Type 2, 4 and 5 equiv. |
| 6 | Chalumbin-Woree power corridor | Mesophyll vine forest [Type 2a], fringing [Type 13c] vine forest; emergent *Eucalyptus grandis* on ridges | 4 | <1 km from Type 3, < 2km from Type 4 equiv. |
| 7 | Mt. Baldy | Simple notophyll vine forest [Type 8] | 1, 5 | <1 km from Type 1, 2, 4 and 5 |
| 8 | Mt. Baldy | [Type 14] | 1 | Type 5, < 250m from Type 4 |
| 9 | Mt. Baldy | Simple microphyll vine-fern forest [Type 9], surrounded by tall *Eucalyptus* forest [Type 14] | 2 | <1 km from Type 1, 2, 3, 4 and 5 |
| 10, 11 | Mt. Baldy | [Type 14b] | 1 | Type 4 |
| 12 | Mt. Baldy | Simple notophyll vine forest [Type 8] | 1 | <1km to Type 1 and Type 4 |
| 13 | Moomin | [Type 14b] near Simple notophyll vine forest [Type 8] | 1 | Type 4 |
| 14 | Tinaroo | [Type 14] | 1 | Type 5, < 100m from Type 4 |
| 15 | Mt. Hypipamee | Complex notophyll vine forest [Type 5a] | 1 | <1 km from Type 1, 2, 4 and 5 |
| 16, 17 | Mt. Fisher | Complex mesophyll/notophyll vine forest [Type 1b/5b] | 1,7 | <4 km from Type 1, 2, 4 and 5 |
| 18 | Ravenshoe | Complex notophyll vine forest [Type 5a] | 1 | <3 km from Type 1, 2, 4 and 5 |
| 19 | Nitchaga | [Type 13c] | 1 | Type 2/3, <150m from Type 4 |
| 20 | Koombooloomba | Simple notophyll vine forest [Type 8] with patches of flooded gum emergent on acid plutonic soil [Type 13c] | 1,5 | Type 3, < 800m from Type 1 and Type 4 |
| 21 | Koombooloomba | [Type 13c] | 1 | Type 2, <500m from Type 1 and Type 4 |
| 22 | Dalrymple Gap | Mesophyll vine forest [Type 13f] close to [Type 15b] | 1 | <100m from Type 4 equiv. |
| 23 | Wallaman Falls | Simple notophyll vine forest [Type 8] | 6 | <4 km from Type 4 and 5 |
| 24 | Paluma | [Type 14a] | 1 | Type 1, < 100m from Type 4 |
| 25 | Paluma | [Type 14] | 8 | Type 5, < 100m from Type 4 |
| 26 | Iron Range | Mesophyll vine forest | 1, 9 | < 1km from Type 4 equiv. |

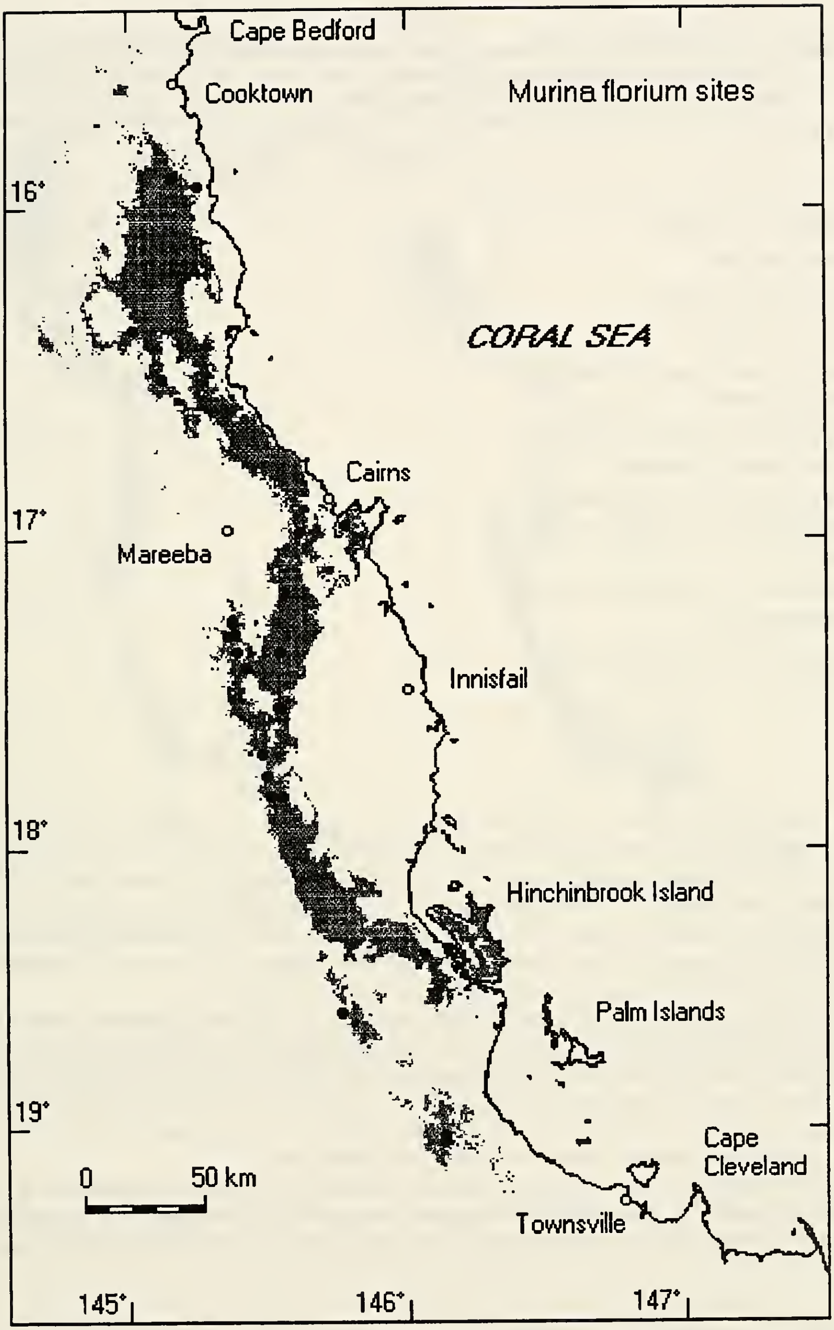


Figure 1. Map of all recorded sites (n=25) for *Murina florium* in the wet tropics region of Australia (listed in Table 2) shown as filled dots. Grey area is the total predicted distribution for *M. florium* using a BIOCLIM model based on the seven climate parameters listed in Table 5 for all localities. The BIOCLIM climate model covers a land surface area (including islands) bounded approximately by the map (Cape Bedford to Cape Cleveland) and up to 120 km inland. This area contains the wet tropics region of Australia as defined by Nix and Switzer (1991).

TABLE 4.

Summary of the major forest structures encountered at *Murina florium* sites, taken from the detailed descriptions in Table 3. Examples of Forest Type are taken from Table 3 using Tracey (1982) and Harrington and Sanderson (1994) classifications. Site numbers (Site No.) are identified in Tables 2 and 3.

| Forest Structure | Forest Type | | Site No. |
|---|---|---|---|
| | Tracey 1982 | Harrington and Sanderson 1994 | |
| Microphyll vine-fern forest | 9 | | 9 |
| Notophyll vine forest | 5a, 5b, 8 | | 1, 7, 12, 15, 18, 23 |
| Meso/notophyll vine forest | 1b/5b | | 16, 17 |
| Mesophyll vine forest | 1a, 2, 3b | | 2, 5, 6, |
| *Eucalyptus grandis* forest with a rainforest substory or understory | 13c | 3, 4 | 19,20, 21 |
| Mixed upland wet sclerophyll forest with a rainforest substory or understory | 14 | 5 | 4, 8, 14, 25 |
| Lowland equivalent of mixed upland wet sclerophyll forest with a rainforest substory or understory | 13f | | 22 |
| Mixed upland wet sclerophyll forest with a grassy ground layer | 14b | 4 | 3, 10, 11, 13 |
| *Eucalyptus grandis* forest with a grassy ground layer | 14a | 1 | 24 |

range 32.6–35.6 mm (n=14); body weight 7.4 g, range 5.8–9.0 g (n=13); tail length 33.9 mm, range 30.8–37.0 mm (n=11); thumb length 8.8 mm, range 6.8–10.1 mm (n=8); 3$^{rd}$ metacarpal 31.6 mm, range 29.2–34.8 mm (n=8); tibia length 16.9 mm, range 15.2–18.8 mm (n=8); ear length 12.5 mm, range 10.5–13.7 mm (n=8). Compared to the holotype of *M. f. florium* (Thomas 1908; Hill 1983), these Australian specimens are similar in the length of the forearm, 3$^{rd}$ metacarpal and tail, but apparently the thumb is longer in the holotype which is also much lower in body weight (see Table 1).

Also shown in Table 1 are measurements of *M. florium* specimens from Papua New Guinea, representing the closest region of collection to Australia. From a very limited sample, their size is generally in agreement with the Australian specimens, and any differences are not consistently larger or smaller. Specimens collected from several Indonesian islands, including the type locality (Flores Is.), are shown in Table 1, but only body weight and forearm length are useful for comparison.

Finally, measurements from a single *Murina* specimen collected at Iron Range (Table 2) generally fall within the range of the other *M. florium* from Australia, and Papua New Guinea, but notably it has a lower body weight and shorter head-body length (Table 1).

### Identification of *M. florium* sites, vegetation and forest type

A total of 25 discrete localities for *M. florium* have been found in the wet tropics region of Australia, as listed in Table 2. One subset of records (n=11) is based on captures where individual bats have been trapped and taken as voucher specimens, or released. The second subset of records (n=14) is based on the presence of *M. florium* at a

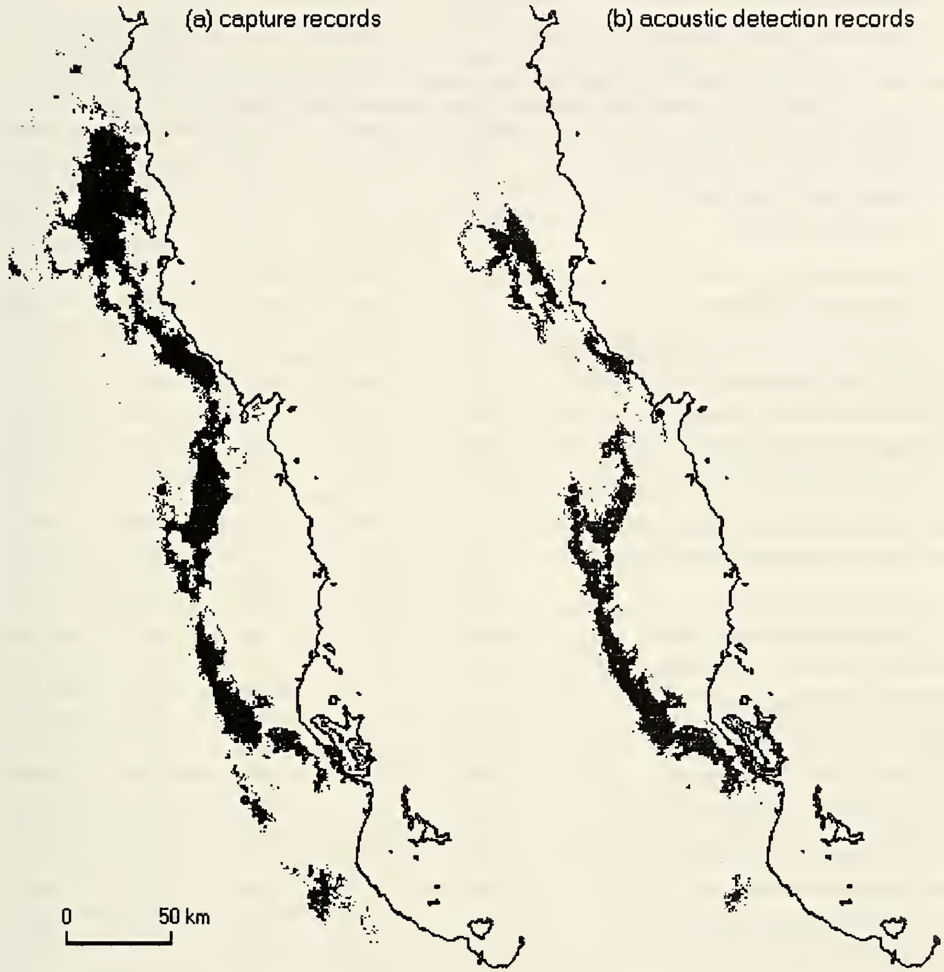


Figure 2. (a) capture localities (n=11) of *Murina florium* for wet tropics sites listed in Table 2, shown as filled dots. Grey area is the total predicted distribution for *M. florium* using a BIOCLIM model based on the seven climate parameters listed in Table 5 for capture sites only. (b) acoustic detection localities (n=14) of *M. florium*, details as in (a). Predicted distribution applies to acoustic detection sites only. For further details see Fig.1.

given site, having been detected acoustically by its echolocation call or social call. Both of these sounds are produced by *M. florium* leaving the diurnal roost or flying in the foraging area at night (Coles et al. 1998). Sound recordings were made at ground level as well as from canopy towers with microphones elevated into the forest strata at various heights (e.g Sites 5 and 17 in Table 2; see Whybird 1996, 1998). Echolocation calls can be used to positively identify free flying *M. florium* by reference to tape recordings (and analysis) from captured, and then released, individuals (Coles et al. 1998). A distinctive social call used by *M. florium* can be recognised in the field with practice, since it is audible to the unaided ear (Winter 1991; Schulz and Hannah 1996; Coles et al 1998). The same call is used by captive bats and released individuals, and it has been recorded and analysed as a means of identifying flying *M. florium,* but its function remains

TABLE 5.

The climate profile for *Murina florium* generated by BIOCLIM using a full set of 35 parameters (see http://cres.anu.edu.au/software/anuclim.html) and based on 25 locations (see Table 2). The predicted distribution of *M. florium* (Figs. 1 and 2) is generated by using a subset of seven key parameters marked by an asterisk (*). For details see text. Temperature in $^{0}$C, Precipitation in mm, Radiation in $m^3/m^3/d$

| | Climate parameter | mean | SD | maximum | minimum | range |
|---|---|---|---|---|---|---|
| 1 | Annual Mean Temperature* | 20.1 | 1.64 | 24.3 | 18.6 | 5.7 |
| 2 | Mean Diurnal Range* | 9.6 | 0.91 | 10.4 | 7.1 | 3.3 |
| 3 | Isothermality* | 0.54 | 0.02 | 0.57 | 0.5 | 0.07 |
| 4 | Temperature Seasonality | 1.01 | 0.08 | 1.15 | 0.82 | 0.33 |
| 5 | Maximum Temperature of Warmest Period* | 28.6 | 1.13 | 31 | 27.3 | 3.7 |
| 6 | Minimum Temperature of Coldest Period | 10.9 | 2.12 | 16.7 | 9.2 | 7.5 |
| 7 | Annual Temperature Range* | 17.7 | 1.48 | 19.0 | 13.9 | 5.1 |
| 8 | Mean Temperature of Wettest Quarter | 22.9 | 1.57 | 26.8 | 21.4 | 5.4 |
| 9 | Mean Temperature of Driest Quarter | 17.7 | 2.01 | 21.9 | 15.4 | 6.5 |
| 10 | Mean Temperature of Warmest Quarter | 23.3 | 1.52 | 27 | 21.8 | 5.2 |
| 11 | Mean Temperature of Coldest Quarter | 16.1 | 1.81 | 21.1 | 14.6 | 6.5 |
| 12 | Annual Precipitation* | 1852 | 333 | 2574 | 1197 | 1377 |
| 13 | Precipitation of Wettest Period | 384 | 73 | 558 | 287 | 271 |
| 14 | Precipitation of Driest Period* | 39 | 11 | 59 | 20 | 39 |
| 15 | Precipitation Seasonality | 85 | 9 | 100 | 70 | 30 |
| 16 | Precipitation of Wettest Quarter | 1063 | 188 | 1486 | 766 | 720 |
| 17 | Precipitation of Driest Quarter | 127 | 37 | 203 | 64 | 139 |
| 18 | Precipitation of Warmest Quarter | 869 | 137 | 1123 | 638 | 485 |
| 19 | Precipitation of Coldest Quarter | 168 | 59 | 290 | 79 | 211 |
| 20 | Annual Mean Radiation | 19.6 | 0.18 | 20.1 | 19.3 | 0.8 |
| 21 | Highest Period Radiation | 24.9 | 0.23 | 25.2 | 24.4 | 0.8 |
| 22 | Lowest Period Radiation | 14.6 | 0.27 | 15.2 | 14.2 | 1 |
| 23 | Radiation Seasonality | 18 | 0.79 | 19 | 16 | 3 |
| 24 | Radiation of Wettest Quarter | 19.7 | 0.48 | 20.8 | 18.9 | 1.9 |
| 25 | Radiation of Driest Quarter | 19.7 | 1.37 | 21.4 | 18.2 | 3.2 |
| 26 | Radiation of Warmest Quarter | 21.7 | 0.42 | 22.6 | 20.9 | 1.7 |
| 27 | Radiation of Coldest Quarter | 16.5 | 0.24 | 17 | 16.1 | 0.9 |
| 28 | Annual Mean Moisture Index | 0.82 | 0.07 | 0.93 | 0.65 | 0.28 |
| 29 | Highest Period Moisture Index | 1 | 0 | 1 | 1 | 0 |
| 30 | Lowest Period Moisture Index | 0.31 | 0.14 | 0.59 | 0.14 | 0.45 |
| 31 | Moisture Index Seasonality | 33 | 11.5 | 58 | 14 | 44 |
| 32 | Mean Moisture Index of Highest Quarter | 1 | 0 | 1 | 1 | 0 |
| 33 | Mean Moisture Index of Lowest Quarter | 0.43 | 0.16 | 0.74 | 0.14 | 0.6 |
| 34 | Mean Moisture Index of Warmest Quarter | 0.91 | 0.03 | 0.94 | 0.8 | 0.14 |
| 35 | Mean Moisture Index of Coldest Quarter | 0.92 | 0.13 | 1 | 0.54 | 0.46 |

unknown. It should be noted that the acoustical structure of the social call is different to a superficially similar vocalisation often used by *Nyctimene robinsoni* in the same areas (Coles et al. 1998).

Vegetation structure at each site was assessed using the Tracey (1982) classification scheme, either directly by visitation, or by reference to previous descriptions (Tables 3 and 4). As well, the scheme proposed by Harrington and Sanderson (1994) for wet sclerophyll forests was used at each site, and where possible, the forest type or an equivalent was defined. The forest in the vicinity of the site was assessed for example, by estimating the distance to the nearest wet sclerophyll forest type or that of an equivalent structure (Harrington and Sanderson 1994).

The rationale for using each classification scheme is that forest types in the humid tropics were defined originally by Tracey (1982), reflecting a combination of the general structure with a finer resolution based on floristics and geological components. Tracey (1982) forest structural types at *M. florium* sites encompass a range of canopy leaf size from 2.5–7.5 cm long (microphyll), up to 12.5–25 cm long (mesophyll). More recently, Harrington and Sanderson (1994) have defined forest types restricted almost entirely within Tracey (1982) forest Type 14 (tall open forest). Harrington and Sanderson (1994) definitions include other Tracey (1982) forest types (e.g. Type 13), but their scheme is based on the successional change from wet sclerophyll forest to rainforest as a function of fire regime. The Harrington and Sanderson (1994) classification scheme can be considered to be both floristic and structurally based, emphasising the dominant living tree species and the status of the forest understory.

Detailed site descriptions using these two schemes are shown in Table 3 and summarised in Table 4. In terms of major forest type, 10 out of 25 sites occurred in rainforest described as notophyll or mesophyll vine forest, whilst five sites (Sites 3,10,11,13 and 24) were located in wet sclerophyll forests. Seven out of 25 sites occurred in forests derived from the invasion of wet sclerophyll forests by rainforest tree species. One site (Site 22) belongs to a lowland equivalent of the upland wet sclerophyll forests. The remaining site (Site 9, Tables 2 and 3), which is the original *M. florium* capture site on Mt. Baldy, was described as microphyll vine-fern forest by Richards et al. (1982), but this description could not be confirmed during the present study. Another nearby capture site on Mt. Baldy (Site 7, Tables 2 and 3) was first described as simple mesophyll vine forest (Schulz and Hannah 1996) but later described as simple microphyll vine-fern forest (Schulz and Hannah 1998; see also Site 20, Table 3). It is difficult to assess the forest types at the Mt Baldy sites, as the published locations are within areas of notophyll vine forest, where smaller patches of Type 9 (microphyll) forest (Tracey 1982) may well exist. The sites established on Mt. Baldy in this study (Sites 8,11 and 12, Tables 2 and 3) are definitely in notophyll vine forest (Tracey 1982: Type 8) or in wet sclerophyll forests (Harrington and Sanderson 1994: Types 4 and 5).

Considering capture records only (refer to Table 2), only two out of the 11 sites were located within the wet sclerophyll forests as defined by Harrington and Sanderson (1994), but a further six sites were located within 4 km of these forest types (Tables 3 and 4). This means that a high proportion (73%) of capture sites involve tropical upland wet sclerophyll forest. More specifically, it should be noted that all of the eight sites mentioned above are within 4 km of Harrington and Sanderson (1994) Type 4 forest (mixed wet sclerophyll forest with a grassy understory). A similar trend can be found for acoustic detection records (refer to Table 2), where 12 out of 14 sites (86%) either belong to a wet schlerophyll forest type as defined by Harrington and Sanderson (1994), or they are located within 4 km of these forest types (Tables 3 and 4).

Considering all sites presented in this study, almost half (48%) are located within a Harrington and Sanderson (1994) defined wet schlerophyll forest type (summary in Table 4), but this proportion increases substantially to 84%, if the presence of wet sclerophyll forest types within a 4 km radius of the sites are included, particularly Type 4

(Table 3). This forest type is one of the most common representatives of upland tropical wet sclerophyll forest in the region, and forms part of a well defined transitional zone (Harrington and Sanderson 1994; Williams and Marsh 1998); the sites in question range in altitude from 580 m to 1120 m above sea level (refer Tables 2, 3 and 4).

Localities at Shipton's Flat, Gap Creek, Gordonvale and Dalrymple Gap (Table 3) appear to be exceptions as they are all lowland sites, ranging from 70 m to 245 m above sea level. However, each site is within 1 km of areas dominated by either acacia or eucalyptus forest that are structurally analogous to the Types 4 and 5 upland mixed wet sclerophyll forests of Harrington and Sanderson (1994).

## Climate modelling

Predicted distributions

A BIOCLIM analysis was performed for all site localities (Table 2) using the full set and a subset of seven climate parameters, as listed in Table 5, to generate a prediction for the preferred habitat of *M. florium.* The subset was chosen by reference to the previous BIOCLIM analysis by Nix and Switzer (1991) and produced a predicted distribution being closely matched to the parent distribution (all parameters) but less restricted in some regions. The predicted area (Figs1 and 2) is described below, with reference to geographical landmarks and relevant *M. florium* sites (see Tables 2 and 3).

The main feature of the predicted distribution (Fig.1) is a series of more or less contiguous zones forming an elongated band along a relatively narrow north-south axis. This band is about 30 km wide at its maximum in the north but mostly it is less than 15–20 km wide and contains numerous discontinuities. In the north, the main zone starts at the approximate latitude of Helenvale (Sites 1 and 2) and then runs west of the Thornton Range incorporating the periphery of the Mt. Windsor and Mt. Carbine Tablelands (Sites 3 and 4), before narrowing through the MacAlister Range (known as the Black Mountain Corridor). The predicted zone extends further southwards into the Lamb Range (Site 6) to the west of Cairns, but it also spreads (patchily) directly to the east into the northern end of the coastal Malbon Thompson Range (Site 5). The main band of prediction continues south through the Atherton Tableland (Site 14) and most of the Evelyn Tableland (Sites 16 and 17), including the Herberton Range to the west (Sites 7–13). Then, the distribution extends in a restricted band along the Cardwell Range, initially rather narrow at the northern end (Sites 18–21), but widens to 20 km or so at the southern end of the range. At this point, the predicted distribution bifurcates, with the main arm heading south eastwards to the coast near Cardwell (Site 22) to include Hinchinbrook Island; some smaller islands are predicted, such as Goold, Brook and the Palm Islands group. At this latitude, the second branch of the predicted distribution remains about 50 km from the coast, proceeding southwards into parts of the Seaview Range (Site 23) and then finally to sections of the Paluma Range (Sites 24 and 25).

In order to validate the use of acoustic detection records for determining *M. florium* localities, a comparison was made between the two methods of observation as they are independent (capture being definitive for this species). The results are shown in Fig. 2 and the predicted map generated by a BIOCLIM analysis for acoustic detection records (Fig. 2b) is quite similar to the one for capture records (Fig. 2a). Both methods of determining the location of *M. florium* in the wet tropics can be seen to augment the ability to predict its habitat.

However, there are significant differences; for example the acoustic detection records available for this study (Table 2) fail to predict substantial areas of lowland forest north of the Mt. Windsor Tableland and to the west of the Thornton Range (compare Figs 2a and 2b). The existence of capture sites at Shipton's Flat and Gap Creek (Table 2, Sites 1 and 2) provide the basis for predicting the lowland distribution of *M. florium* north of the Mt. Windsor Tableland. On the other hand, two acoustic detection sites on the Mt. Windsor and Mt. Carbine Tablelands independently confirm predictions made from capture records alone (Fig. 2b). Similarly, the lowland acoustic detection sites at Gordonvale and Dalrymple Gap (Table 2, Sites 5 and 22) are predicted by the distribution generated from capture records (see Fig. 2a).

A further comparison between the predicted distributions in Fig. 2 reveals that capture records suggest a wider area in the MacAlister Range compared to acoustical detection records. Capture records predict a possible discontinuity between the Herberton and Cardwell Ranges, but *M. florium* was detected acoustically in this area. Interestingly, acoustical records alone did not predict suitable habitat for *M. florium* in the Seaview Range, but there is a capture record in this region at Wallaman Falls (Fig. 2a; Site 23, Table 2). *M. florium* has been reported from the Paluma Range by both capture and acoustical detection (Table 2), but capture records alone predict a greater area of potential habitat (compare Figs 2a and 2b).

Within the boundary of the present BIOCLIM model and predicted distribution (Fig. 1), there are a few isolated areas of potential significance: the Lookout Range, west of Cooktown; an unnamed range west of the Mt. Windsor Tableland and just east of the Peninsula Developmental Road; a possible presence at Baker's Blue Mountain and Hanns Tableland.

### The climate profile for *Murina florium*

The climate surfaces that generate a predicted distribution for *M. florium* (Figs 1 and 2) are based on variations in rainfall and temperature for seven out a possible 35 parameters (Table 5, see Methods). These parameters appear to have the greatest predictive value (see also Nix and Switzer 1991) and thus the distribution shown in Fig.1 is determined by a combination of annual precipitation and precipitation in the driest period, together with the annual mean temperature and the maximum temperature of the warmest period. In addition, the derived variables of annual temperature range, mean diurnal range and isothermality contribute significantly to the predicted distribution. It should be noted that the climate model proposed here, and its predictions, take into account all the variation between the known localities for all seven parameters. This is in contrast to specifying a bioclimatic 'core' and 'margin' to predict the distribution of vertebrates endemic to the same region (Nix and Switzer 1991).

The climate profile produced by the present study (Table 5), at least in the wet tropics of Australia, suggests that *M. florium* is likely to be found in regions with a moderate to high annual rainfall varying between 1197 mm and 2574 mm, and areas where rainfall over the driest period ranges from 20 mm to 59 mm. *M. florium* appears to prefer an annual mean temperature between 18.6°C to 24.3°C with an average annual and diurnal range of 13.9°C to 19.0°C and 7.1°C to 10.4°C respectively.

### The Iron Range locality

As the identity of the *Murina* specimen collected from Iron Range is similar in many respects to *M. florium* (see above for description, below for Discussion; also Hill and Rozendaal 1989), it is considered here as an outlier to the main population in Australia. Limited by dealing with a single specimen, it is nevertheless useful to consider the climate and vegetation that apply to the collecting site.

The site locality is known (Table 2) and the closest available climate measurements come from the Lockhart River Airport (12°47′S 143°18′E, elevation 17.4 m) located at a distance of 10 km. Climate statistics (Bureau of Meteorology 1999; for the period 1956 to 1999) are: mean annual rainfall, 2087 mm; precipitation for the driest period, 30 mm; mean daily maximum temperature for warmest quarter 31.7 °C; mean annual temperature, 25.8 °C. On this basis, the Iron Range collecting locality appears to fall within the maximum and minimum values for two of the most important rainfall and temperature parameters determined by the climate profile in the wet tropics (Table 5). The maximum temperature of the warmest period and annual mean temperatures are higher but nevertheless close the climate profile (Table 5).

Vegetation at the capture site is an area of mesophyll vine forest (Tracey 1982), and it is located within 1 km of wet sclerophyll forest, equivalent to a Harrington and Sanderson (1994) Type 4 (J. Clarkson, pers. comm., see Table 3). This locality is thus similar to other *M. florium* sites in the wet tropics region, such as Gap Creek (Site 2) and Dalrymple Gap (Site 22); for details see Tables 2, 3 and 4, and Fig.1.

## DISCUSSION

### The occurrence of *Murina florium* in Australia

From a comparison of the measurements obtained from *Murina* specimens listed in Table 1, it is most likely that a single species, *Murina florium,* occurs in Australia. At present, the known populations occur in the wet tropics region (Fig. 1, Table 2; see Nix and Switzer 1991) although tentatively, a single specimen collected from Iron Range on Cape York Peninsula may be the same species (cf. Richards et al. 1995), representing a northern Australian population. To confirm this view, more specimens are needed for a detailed morphometric and genetic analysis. At present, it seems reasonable to conclude that the Australian *M. florium* population represents the south eastern distributional limit of the species, as part of a continuum with the Papua New Guinea population. It is not possible to say conclusively if the Australian population differs significantly from the holotype (Thomas 1908) or other specimens collected from a number of eastern Indonesian islands (Table 1). The question of subspecies can not be resolved here, beyond the opinions of Van Deusen (1961) who considered that possibly only one species of *Murina* exists east of Wallace's Line, and that of Hill and Rozendaal (1989) who suggested one subspecies, *M. f. lanosa,* to be valid in this region. However, it can be stated that *M. florium* is not confined to high altitude forests in Australia as previously believed (Richards 1983, 1991) because specimens have been collected at elevations below 300m (Tables 1 and 2). Elsewhere, *M. florium* has been collected from localities close to sea level (Ambon Is. Indonesia; see Table 1; Flannery 1995b) although the species certainly inhabits high altitude areas as well e.g. at 1480 m on Mt. Somoro, Papua New Guinea (see Table 1 and Flannery 1995a).

### The distribution of *Murina florium* in Australia

Habitat preference and climate

Despite a relatively limited sample of sites in Australia, it would appear that *M. florium* is found in tropical forests that share several notable features (Tables 3 and 4). Of course, each site in this study identifies *M. florium* only at a single point in the forest, but the location is useful to describe at least part of its habitat. Despite some variability in forest structure at the site (Tables 3 and 4), *M. florium* is found predominantly in rainforest where wet sclerophyll forest is in close proximity, or in wet sclerophyll forest itself (Table 3). This finding is consistent for upland areas containing wet sclerophyll forest and extends to their counterparts in lowland forest. It suggests that *M. florium* may show some association with a transitional zone involving Type 4 mixed wet sclerophyll forest (Harrington and Sanderson 1994) or its structural equivalent (see Tables 3 and 4). The distribution of these forest types is limited in the wet tropics of Australia and often the forest boundaries are sharply demarcated (Harrington and Sanderson 1994). Within this ecotone, vertebrate diversity has been found to change significantly across the transition from open forest into rainforest (Williams and Marsh 1998). In the case of bats in general, diversity has been found to be high in Type 4 forests in the region compared to rainforest, and in fact, the northern populations of species such as *Tadarida australis*, *Nyctophilus gouldi* and *Scoteanax rueppellii* appear to be restricted to these wet sclerophyll forests (Clague 1998).

Interestingly, both the distribution of tall open forest types (Harrington and Sanderson 1994) and the predicted distribution for *M. florium* (Fig. 1) tend to be adjacent to the wettest areas in the region experiencing a significantly lower rainfall regime (Nix and Switzer 1991). For example, all *M. florium* sites studied here, except Dalrymple Gap and the Chambullan-Woree power corridor site (Table 2), are located on the western slopes or plateaus of mountainous areas (Fig. 1 and see Nix and Switzer 1991). Climatically, these sites occur in a steep rainfall gradient: refer to Table 5, and compare Fig.1 in this study with Fig.11 of Nix and Switzer (1991). In this respect, the Dalrymple Gap site (Site 22, Table 2, and see Fig.1) is most likely within a rain shadow caused by its proximity to the mountainous Hinchinbrook Island. Likewise, the Chambullan-Woree power corridor site (Site 6, Table 2, and see Fig.1) is likely to receive less precipitation compared to adjacent peaks in the Lamb Range, due to the convoluted topography of the area (see Fig 11 in Nix and Switzer 1991).

Modelling the variation between sites via BIOCLIM produces a climate profile that can be defined by as few as seven parameters of rainfall and temperature (Table 5). Each climate surface has been used to find an area that is common to all sites and the model predicts a highly restricted distribution for *M. florium* (Fig.1), one that appears to encompass most, if not all, of the 'preferred' habitat described above (see Tables 3 and 4). Of course, the reliability of the predictions are unknown, due to limited and potentially biased sampling. If the predictions are accurate, then it suggests that the distribution of *M. florium* in Australia is clearly influenced by the climate which must exert a major control over suitable forest habitat.

Although not specifically included in this study, it would seem that the outlying Iron Range capture site is a reasonable match to the climate and vegetation pattern established for *M. florium* in the wet tropics (Tables 3 and 5). Extending the BIOCLIM analysis to include the entire Cape York Peninsula would be of great interest, to see if suitable habitat can be predicted, and to serve as a focus for future field surveys. It was noted that a number of coastal continental islands are predicted (see Results and Fig. 1), the largest of these being Hinchinbrook Island. The predicted islands in this vicinity all contain mesophyll vine forest, as well as equivalent mixed wet sclerophyll (Harrington and Sanderson 1994). Therefore, it would not be surprising to find *M. florium* on these islands, none of which have been surveyed for bats in any detail (see Myroniuk 1988).

Roost preference

A comparison of site vegetation (Tables 3 and 4) and a climate analysis (Figs 1 and 2, Table 5) support the idea that *M. florium* may show a habitat preference. Whilst the localities identified in the present study are likely to be part of an individual bat's foraging area, a given forest type or combination of forest types might also provide suitable diurnal roosts. There are no data on the exact foraging range of *M. florium,* but Schulz and Hannah (1998) report roosts to be located within 150–900 m of capture sites. Since almost all of the sites in this study have been found in close proximity to Type 4 (Harrington and Sanderson 1994) forests (see Table 3), forest type might have an important bearing on roost selection. In this regard, *M. florium* has been found to roost in trees 'externally', under foliage such as dead epiphytic fern fronds (Type 2 forest of Harrington and Sanderson 1994) and palm leaves, as well as in the abandoned nests of *Sericornis citreogularis* and *Oreoscopus gutturalis* (Schulz and Hannah 1998). A tendency to roost in suspended bird nests may be an important clue, as it has been suggested that the northern population of *S. citreogularis* may be restricted to upland wet sclerophyll forests (Harrington and Sanderson 1994), and the distribution of this scrub wren may well coincide with that of *M. florium.* Moreover, the predicted distribution of *O. gutturalis* is remarkably similar to that predicted for *M. florium*, at least for upland areas (compare Fig.1 this study, with page 60 in Nix and Switzer 1991). Other bird nests may prove suitable as well and recently *M. florium* has been found roosting in the nest of *Todiramphus sanctus* burrowed into a termite mound, suspended in a tree, in mixed sclerophyll forest (Type 4) on Mt. Baldy (Clague, unpublished observations).

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## REFERENCES

Bureau of Meteorology (1999). Bureau of Meteorology, Australia. Climate Averages, http://www.bom.gov.au.

Busby, J.R. (1986). BIOCLIM — a bioclimatic analysis and prediction system. In: Margules, C. R. and Austin, M. P. (ed.) Nature Conservation: Cost Effective Biological Survey and Data Analysis. CSIRO Melbourne 64–68.

Churchill, S. (1998). 'Australian Bats'. Reed New Holland, Sydney.

Clague, C.I. (1998). The differential utilisation of forest types by insectivorous bats in far north Queensland wet sclerophyll forests. *Bat Research News* **39**, 30.

Clague, C.I. (2000). The Tube-nosed Insectivorous Bat. *Nature Australia* **26**, 22–23.

Clague, C.I., Coles, R.B. and Spencer, H.J. (1995). Survey of bat fauna in the Wet Tropics World Heritage Area of north Queensland, Australia. *Bat Research News* **36**, 14.

Coles, R.B., Clague, C.I., Whybird, O.J. and Spencer, H.J. (1998). Echolocation and social calls of *Murina florium. Bat Research News* **39**, 9.

Corbett, G.B. and Hill, J.E. (1992). 'The mammals of the Indomalayan region, a systematic review'. Natural History Museum Publication, Oxford University Press, New York.

Duncan, A., Baker, G.B. and Montgomery, N. (1999). 'The action plan for Australian bats'. Environment Australia, Canberra.

Flannery, T.F. (1995a). 'Mammals of New Guinea'. Reed Books, Sydney.

Flannery, T.F. (1995b). 'Mammals of the South-West Pacific and Moluccan Islands'. Reed Books, Sydney.

Hall, L.S. (1983). 'A study of the status, habitat requirements and conservation of rare and endangered Australian bats'. Project 33. World Wildlife Fund Australia.

Harrington, G.N. and Sanderson, K.D. (1994). Recent contractions of wet sclerophyll forest in the wet tropics of Queensland due to invasion by rainforest. *Pacific Conservation Biology* **1**, 319–327.

Hill J.E. (1983). Bats (Mammalia: Chiroptera) from Indo-Australia. *Bulletin of the British Museum of Natural History (Zoology)* **45**, 103–208.

Hill, J.E. and Rozendaal, F.G. (1989). Records of bats (Microchiroptera) from Wallacea. *Zoologische Mededelingen, Leiden* **63**, 97–122.

IUCN (1994). IUCN Red List Categories. IUCN Species Survival Commission, Gland.

Koopman, K.F. (1993). Chiroptera. In: Wilson, D.E. and Reeder, D.M. (ed.) Mammal Species of the World. 137–242. Smithsonian Institution Press, Washington DC.

Koopman, K.F. and Danforth, T.N. (1989). A record of the tube-nosed bat (*Murina florium*) a new record from western Papua New Guinea (Irian Jaya) with notes on related species (Chiroptera, Vespertionidae). *American Museum Novitates* **2934**, 1–5.

Kutt, A.S. and Burnett, S.E. (1995). Two significant vertebrate fauna records from mid-altitude wet tropical rainforest, Lamb Range State Forest. *Memoirs of the Queensland Museum* **38** (2), 436.

Laurie, E.M.O. and Hill, J.E. (1954). 'List of land mammals of New Guinea, Celebes and adjacent islands 1758–1952'. British Museum of Natural History, London.

Myroniuk, P. (1988). A survey of mammals on Hinchinbrook Island, North Queensland. *Australian Zoologist* **25** (1), 6–10.

Nias, R.C., Kennedy, M., Reynolds, C. and Habel, S. (1993). 'A regional action plan for the conservation of threatened species and ecological communities in the Wet Tropics of Queensland World Heritage Area'. Report to the Wet Tropics Management Authority, Cairns.

Nix, H.A. and Switzer, M.A. (1991). Rainforest Animals: Atlas of Vertebrates Endemic to Australia's Wet Tropics. *Kowari* **1**, 1–112.

Richards, G.C.(1983). Tube-nosed Insectivorous Bat *Murina florium.* In: Strahan, R. (ed.), 'The Australian Museum Complete Book of Australian Mammals'. Angus and Robertson, Sydney 364.

Richards, G.C. (1991). Conservation status of the rainforest bat fauna of northern Queensland. In: Werren, G. and Kershaw, P. (ed.) The Rainforest Legacy. Australian national rainforest study. Volume 2 — Flora and fauna of the rainforest. Australian Government Publishing Service, Canberra. 177–186.

Richards, G.C., Coles, R.B. and Spencer, H.J. (1995). Tube-nosed Insectivorous Bat, *Murina florium.* In: Strahan, R. (ed.) The Mammals of Australia. Australian Museum/Reed Books. Sydney. 496–497.

Richards, G.C., Hall, L.S., Helman, P.M. and Churchill, S.K. (1982). First discovery of a species of the rare tube-nosed insectivorous bat (*Murina*) in Australia. *Australian Mammalogy* **5,** 149–151.

Schulz, M. and Hannah, D.S. (1996). Notes on the tube-nosed insect bat *Murina florium* (Chiroptera: Vespertilionidae ) from the Atherton Tableland, north-eastern Queensland, Australia. *Mammalia* **60,** 312–316.

Schulz, M. and Hannah, D.S.(1998). Relative abundance, diet and roost selection of the tube-nosed insect bat, *Murina florium*, on the Atherton Tablelands, Australia. *Wildlife Research* **25,** 261–271.

Spencer, H.J., Schedvin, N. and Flick, B.M. (1992). Re-discovery of Australia's rarest bat, *Murina florium*, the insectivorous tube-nosed bat, in lowland forest in far north Queensland. *Bat Research News* **33**, 76.

Thomas, O. (1908). New bats and rodents in the British Museum collection. *Annals and Magazine of Natural History* **8,** 370–375.

Tracey, J.G. (1982). 'The vegetation of the Humid Tropical Region of North Queensland'. CSIRO, Melbourne.

Van Deusen, H.M. (1961). A New Guinea record of the tube-nosed insectivorous bat, *Murina*. *Journal of Mammalogy* **42,** 531–533.

Whybird, O.J. (1996). An investigation into the vertical stratification of the Chiroptera of tropical Australian rainforests. Honours thesis. The University of Queensland.

Whybird, O.J. (1998). Methods of sampling forest bats and bat activity above the ground. *Australasian Bat Society Newsletter* **11**, 31–36.

Williams, S.E. and Marsh, H. (1998). Changes in small mammal assemblage structure across a rain forest/open forest ecotone. *Journal of Tropical Ecology* **14**, 187–198.

Winter, J. (1991). Mammals. In: Nix, H.A. and Switzer, M.A. (ed.) Rainforest Animals: Atlas of Vertebrates Endemic to Australia's Wet Tropics. *Kowari* **1**, 43–54.